Annual Report on Estuarine Restoration at East Harbor (Truro, MA), Cape Cod National Seashore, 2008

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INTRODUCTION

The following is excerpted from the 2007 monitoring report (Portnoy et al. 2008):

> East Harbor, a 720-acre back-barrier lagoon comprised of Moon Pond, Pilgrim Lake and Salt Meadow, was artificially isolated from the Cape Cod Bay marine environment in 1868 with the filling of the original 1000-ft wide inlet at the northwest end of the system. A drainage system was installed at the south end of the embayment in 1894 to allow freshwater to escape. The exclusion of tides caused salinity to decline from a likely natural condition of 25-30 parts per thousand (ppt) to nearly freshwater conditions, at least by the time of the first documented fish survey in 1911. By this time the native estuarine fauna were largely extirpated; the State Survey of Inland Waters (1911) recorded "German carp and very few eels and shiners". The blockage of tides apparently caused water quality to decline rapidly along with salinity: surveys from 1911 to the 1970s reported low salinity (4-10 ppt), high turbidity, probably due to carp feeding and cyanobacterial blooms (Mozgala 1974), nuisance chironomid midge breeding and chronic summertime dissolved oxygen stress (Emery & Redfield 1969, Cape Cod National Seashore 2002).
>
> An oxygen depletion and fish kill in September 2001prompted Truro and Cape Cod National Seashore officials to open the clapper valves in the 4-ft diameter drainage pipe connecting the southeast end of the system (Moon Pond) with Cape Cod Bay (Fig. A) in hopes of restoring some tidal exchange and increasing aeration. These valves have been cabled open almost continuously from November 2002 to the present. Despite limits on tidal exchange imposed by the pipe's small diameter, and the distance that it travels under ground, we have observed an impressive response in the recovery of salinity and estuarine biota.

This report is a summary of monitoring results from 2008 on tide heights, water quality, macroalgae, submerged and emergent vegetation, nekton (fish and decapod crustaceans), and shellfish from 2008. For more details on background information and methodologies, please refer to previous reports (Portnoy et al. 2005-2008) – now available online at:

http://www.nps.gov/caco/naturescience/east-harbor-tidal-restoration-project-page.htm

SALINITY, TEMPERATURE AND DISSOLVED OXYGEN

Stephen Smith and Kelly Chapman

Methods

Details on YSI datalogging methods can be found in Portnoy (2008). Figure 1 shows the permanent locations the tidal creek that runs through Moon Pond and in the main lagoon (Figure 1). Salinity, temperature, and dissolved oxygen were recorded at 30 min intervals between May 21 and Sept 22, 2008.

Figure 1. Map of YSI datalogger stations in the lagoon (left star) and tidal creek (right star).

Results

In 2008 (between the dates of May 21 and Sept 22), temperatures in both the tidal creek and lagoon climbed until the end of July/beginning of August and then fell rapidly during the fall (Figure 1). Large drops in temperature in the creek correspond with periods of spring tides when larger volumes of colder Cape Cod Bay water enter the system. Overall, temperatures in the creek were lower than temperatures in the lagoon.

Salinity showed extensive daily fluctuation in the tidal creek. (Figure 2) While there also was variability in the lagoon over very short time scales, the range was much narrower. The general trends in both parts of the system are the same. Salinity increases to peak values around mid-August and then begins to decline again. The mean salinity of the tidal creek is considerably higher than the lagoon (see best fit lines).

By contrast, dissolved oxygen (DO) exhibited large variation over short time scales throughout the deployment period in both the lagoon and creek (Figure 2). Best-fit curves through each data set revealed that on average DO is slightly lower in the creek than in the lagoon. However, this is due to higher maximum values in the lagoon where daytime photosynthesis (particularly from macroalgae) can be very high. DO was rarely below 50% saturation in either part of the system.

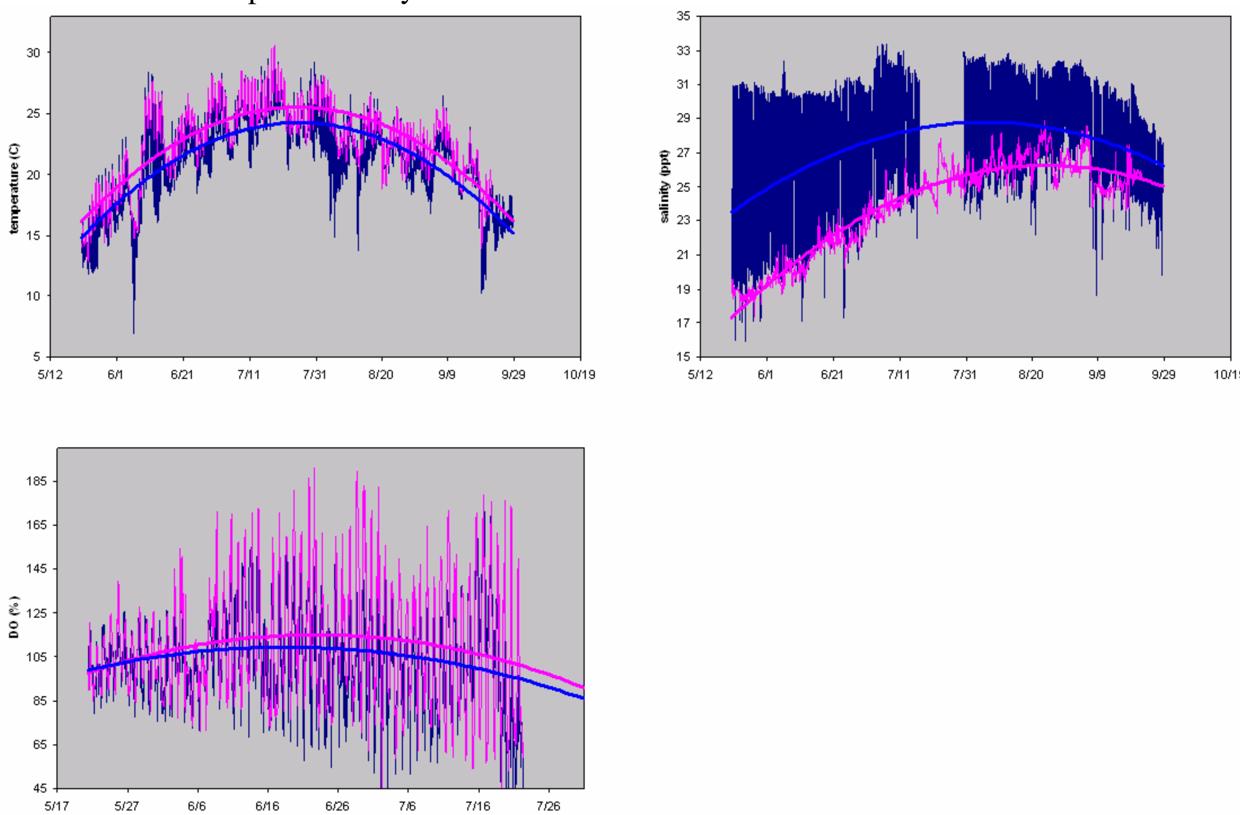


Figure 2. Temperature, salinity, and % dissolved oxygen in the tidal creek (blue) vs. main lagoon (pink) (best fit lines through each dataset indicate the general trends.

Compared to 2007, there were few large differences in minimum, maximum, or mean salinities and temperature (Table 1). By contrast, DO and stage did show relatively large differences. DO in both the lagoon and Moon Pond had a much larger range in 2007 than in 2008. The slight reduction in salinity observed in Moon Pond in 2008 may be due to the higher precipitation that year (Table 2), which would translate into higher groundwater inputs from the surrounding uplands (High Head).

Table 1. Minimum, maximum, and mean temperatures, salinities, and % DO in the lagoon (L) and Moon Pond tidal creek (MP) in 2007 and 2008.

2008	Temp (C)		Salinity (ppt)		DO (%)	
	L	MP	L	MP	L	MP
min	12.8	6.9	16.1	15.3	75	31
max	30.6	29.7	28.9	33.4	192	171
mean	22.7	21.1	23.9	27.1	115	102

2007	Temp (C)		Salinity (ppt)		DO (%)	
	L	MP	L	MP	L	MP
min	14.0	7.7	18.2	15.7	31	3
max	30.2	28.7	30.0	33.4	308	175
mean	22.1	20.8	25.2	27.8	111	92

Diff	Temp (C)		Salinity (ppt)		DO (%)	
	L	MP	L	MP	L	MP
min	-1.2	-0.8	-2.1	-0.4	44.2	27.3
max	0.4	1.0	-1.1	0.0	-116.4	-3.7
mean	0.6	0.3	-1.3	-0.7	3.9	9.7

Table 2. Total monthly precipitation (recorded at Provincetown airport) in inches for May through August 19th of 2007 and 2008 (data for Provincetown station available at www.weatherunderground.com).

	2007	2008	Diff
May	2.83	2.25	-0.58
June	0.86	2.02	+1.16
July	3.22	2.30	-0.92
Aug (19th)	0.33	3.19	+2.86
Total	7.24	9.76	+2.52

II. WATER QUALITY

Krista Lee

Background

For the past two years (2007-2008), monthly surface water quality monitoring has taken place at East Harbor in order to quantify the levels of nutrients and primary productivity (see Figure 3 for sampling locations). In the past, regular monitoring of surface water quality parameters throughout the system did not occur, although limited data are available (total nutrients from May-August 2002 and chemical oxygen demand in 2002-2003), as is salinity data from 1995-1997 (Jones 1997).

Figure 3. Map of 2007-2008 water quality sampling locations.

Methods

A total of 11 stations were sampled on a monthly basis just below the surface (~ 0.2 m) between 10 am and 3 pm on an outgoing tide for the following parameters:

- pH
- specific conductance (µS/cm)
- salinity (ppt)
- dissolved oxygen (% saturation)
- dissolved oxygen concentration (mg/L)
- total dissolved solids (g/L), color (absorbance @ 440nm)
- turbidity (NTU)
- chlorophyll-α (µg/L) (filtered water/acetone extraction/fluorometric detection)
- dissolved inorganic nitrogen (µM) (DIN) (filtered/acidified sample: N as nitrate/nitrite + ammonium)
- total nitrogen (µM) (TN) (whole water sample/persulfate digest: N as NO_3)
- total dissolved nitrogen (µM) (TDN) (filtered sample/persulfate digest: N as NO_3)
- dissolved organic nitrogen (µM) (DON) (calculated by difference: TDN-DIN)
- dissolved inorganic phosphorus (µM) (filtered/acidified: P as PO_4)
- total phosphorus (µM) (TP) (whole water sample/persulfate digest: P as PO_4)
- total dissolved phosphorus (µM) (TDP) (filtered sample/persulfate digest: P as PO_4.

A calibrated hand-held YSI 556 MPS was utilized on station to collect the pH, specific conductance, salinity, total dissolved solids, and dissolved oxygen measurements. A grab sample was collected at each station in clean, triple rinsed, amber 2 liter bottles and stored on ice in a cooler and returned to the lab for immediate processing for all other parameters. Sub-samples were filtered through a 0.45µm filter for all dissolved nutrient species and stored frozen at -20ºC until analysis; sub-samples for total nutrients were frozen at -20ºC until digestion and subsequent analysis. Sub-samples for color were filtered through a 0.45µm filter and analyzed immediately on a Jenway 6305 UV/VIS spectrophotometer at 440nm. Sub-samples for turbidity were analyzed on a calibrated Hach 1200 portable Turbidimeter. Sub-samples for chlorophyll-α were filtered through a 0.45µm glass fiber filter (filtrate volume noted) and filters were immediately placed in vials containing 90% acetone and placed in the dark at 5ºC for extraction of pigment; subsequent fluorometric measurements were taken in 24 hours for chlorophyll-α concentration determination via a Turner Designs Trilogy Fluorometer (USGS SOP #ORGX0337.3, 2005).

Inorganic nutrients (PO_4-P, NH_4-N,$NO_2^-$and NO_3^--N) were determined by Lachat FIA+ 8000 following Lachat Methods 10-115-01-1-M (rev. Aug. 27, 2003), 31-107-04-1-C (rev. Sept. 16, 2003), and 10-107-06-1-C (rev. Nov. 2, 2001), respectively. Total nutrients (nitrogen and phosphorus) were determined by simultaneous digestion with persulfate oxidizing reagent followed by FIA+ 8000 Lachat Methods 31-115-01-1-C (rev. Sept. 16, 2003) and 10-115-01-1-M (rev. Aug. 27, 2003). The USGS WRIR 03-4174 (Method for Persulfate Digestion) was utilized for the digestion of samples. All methods are from Liao 2003, Diamond 2003, and Bogren et al. 2001.

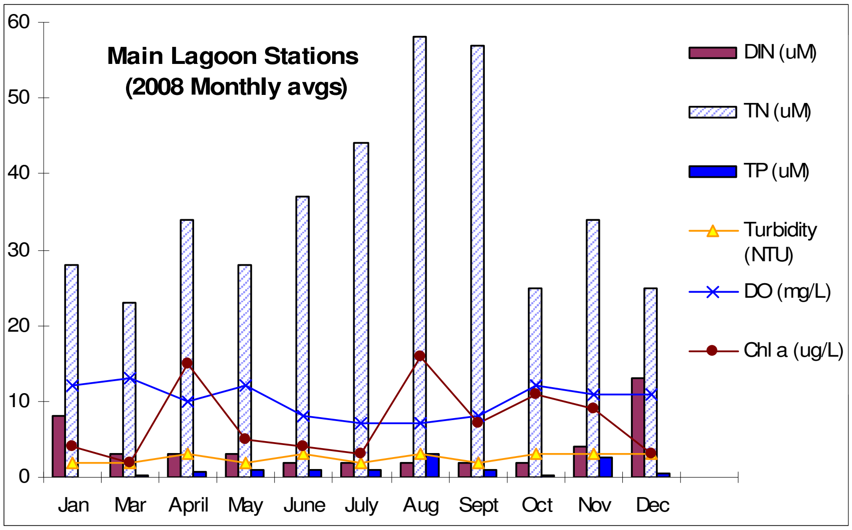
Results & Discussion

In 2008, water clarity in the main lagoon remained relatively clear with mean turbidity ~3 nephelometric turbidity units (NTU) (Figure 4). Surface water temperatures throughout the system ranged from 2ºC in January to 26ºC in July with a mean of 23 ±3ºC from June through August. Salinity at the Salt Meadow drainage area (Sta. 2) averaged 1.5 ± 0.8ppt; all other stations mean 22 ± 3ppt from January-December.

As average surface water temperatures increased approximately four-fold from March (~2ºC) to May (~13ºC) and ice cover completely thawed in March. Mean ammonium levels decreased from approximately ~6µM in January to ~2µM in the spring and mean chlorophyll-α concentrations nearly quadrupled from ~4µg/L (Jan.) to ~15µg/L (April). Chlorophyll- α concentrations also peaked in August at ~16µg/L.

Average surface water dissolved oxygen levels remained consistently high throughout the main water body (~103%) over the course of the year, although Salt Meadow (Sta. 2) dissolved oxygen dropped to less than 50% in June. Increases of Total Phosphorus (TP) concentrations were observed throughout the lagoon (as well as in Salt Meadow) in August and again in November.

The ammonium fraction of DIN dominated the water column in the winter of 2008. Mean DIN values ranged widely from 8µM in January to ~3µM throughout the majority of the field season until December, when values increased once again to ~13µM (Figure 4). The mean molar ratio for DIN:TP during April-November was ~3, indicating that primary productivity in East Harbor was strongly nitrogen limited from April through November (Redfield 1958) (Figure 4). Additionally, mean DIN:TN and DIN:DON from August indicate approximately 3 times more organic nitrogen was present in the surface water than dissolved inorganic species. Results were similar to 2007, demonstrating high export of nitrogen in predominately organic forms during ebb tides (show fig comparing 2007, 2008). This seems to support our 2007 findings that the ultimate source of N is internal and that most of the N has been incorporated into organic compounds.



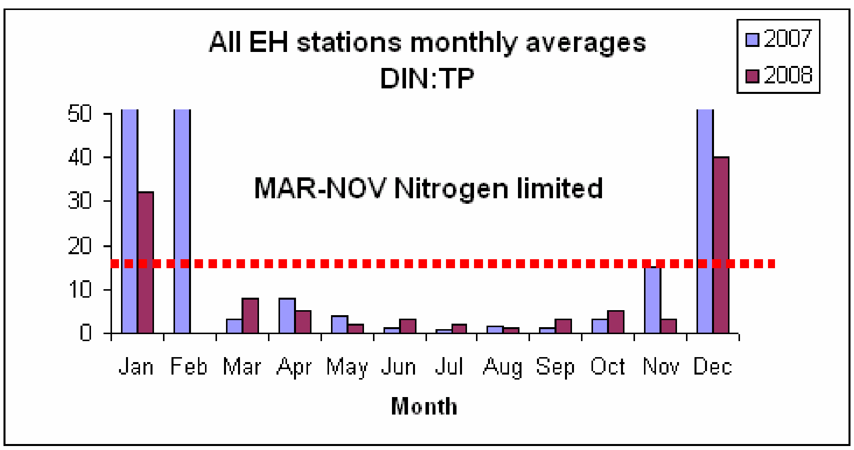


Figure 4. Monthly averages across all Main Lagoon stations (Stations 3-5, 7-10) (top graph) and mean DIN:TP by month (all stations) in 2007 vs.2008 (bottom).

In terms of spatial variation in water quality, the system can be divided into 3 distinct parts consisting of the NW cove, the main lagoon, and salt meadow – a former salt marsh creek that converted to a freshwater creek (as a result of severe tidal flow restriction) that drains into east end of East Harbor. The highest chlorophyll-α concentration measured during the 2008 field season occurred in the more stagnant, shallow Northwest Cove (EH 6) in August (Figure 5). Chl-α ranged from 3µg/L in December, to 54 µg/L in July, and peaked at 130 µg/L in August. Turbidity values during the summer months averaged ~12 NTU for the Northwest Cove as compared to ~3 NTU for the main lagoon. Typically higher levels of TN, DIN, and TP are also measured in the Northwest Cove as compared to the main lagoon. The Salt Meadow (EH 2) drainage area also had greater variation in chlorophyll, turbidity and nutrients, peaking at 60µg/L chl- α in August with summertime turbidity measurements averaging approximately 10 times that of the main lagoon. This iron rich, highly colored, freshwater drainage area also contributes nutrients at concentrations typically 10 and 3 times higher in the summer months than those measured in the main lagoon for TN and TP, respectively. Even though the relative levels of nutrients in the Northwest Cove and Salt Meadow exceed those found in the main lagoon, these areas likewise remain nitrogen limited based on the ratio of DIN:TP (see Figure 4) as compared to Redfield Ratio.

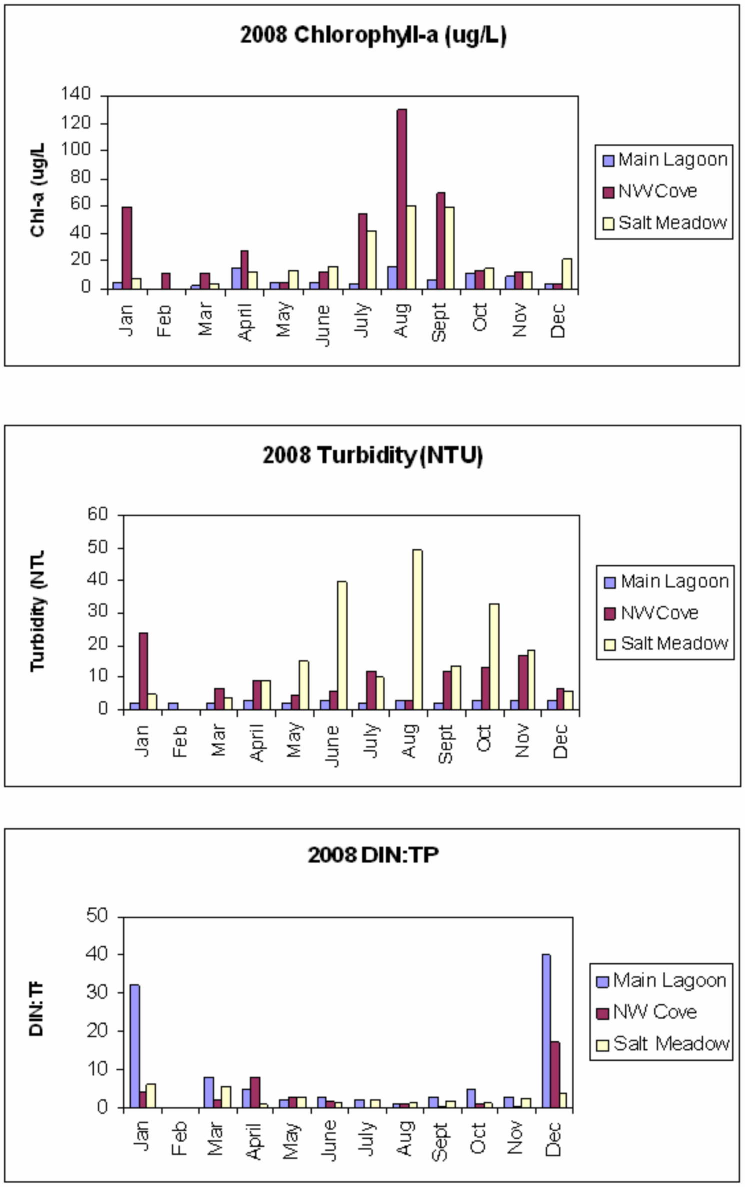


Figure 5. Chlorophyll- α, turbidity and DIN:TP in the main lagoon, NW cove, and Salt Meadow during 2008.

Future water quality analysis and monitoring plans

Monthly surface water monitoring will continue at all stations on a year round basis in 2009 and additional nitrogen flux studies may be completed in early spring 2009.

Literature cited

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III. VEGETATION

Stephen Smith

A detailed overview of vegetation monitoring protocols can be found in Portnoy et al. (2008 and Smith, in press). The following provides an update to these reports based on data collected during the summer-fall of 2008.

Methods

Plant species coverage in the permanent vegetation plots (Figure 6) was assessed by visual estimation of cover class according to a modified Braun-Blanquet scale (0=0, >0-5%=1, 6-25%=2, 26-50%=3, 51-75%=4, 76-100%=5) in August. *Phragmites* maximum stem heights and stem densities for each plot were recorded at the end of the 2008 growing season (September). Biomass was estimated based on regression equations using the two above variables (R^2=0.95). The estimates are very close to those determined from stem densities + the 5 tallest stems as per Thursby et al. (2002).

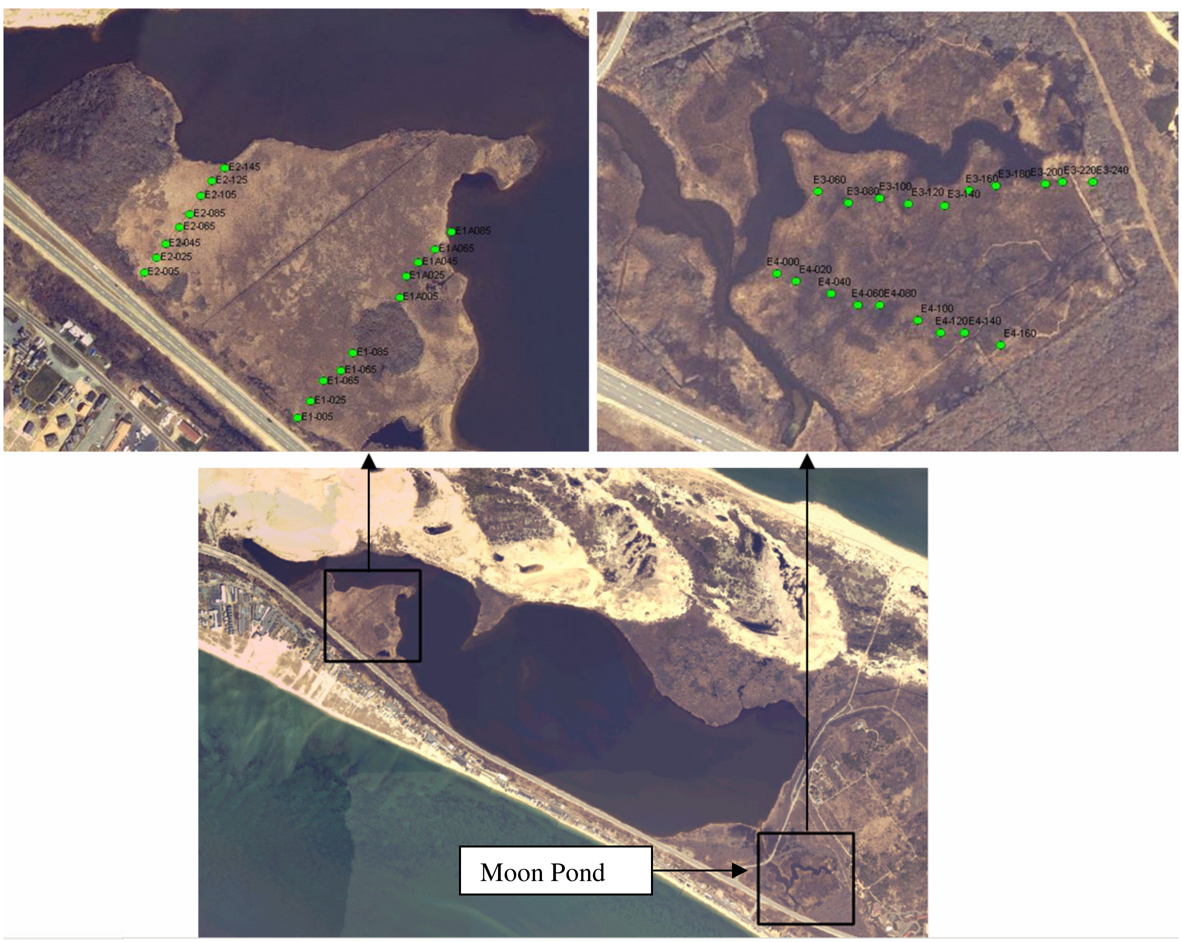

Figure 6. Map of East Harbor with vegetation plot locations along transects EH1 through EH4.

Note: In 2008, 4 new transects (23 plots) were added to the plot network in order to increase coverage of the peripheral marsh area of East Harbor. The1-m^2 plots along these transects start points were randomly selected from along the perimeter of the lagoon. Plots were then randomly spaced along transects in the southeast and northwest peripheral marshes (Figure 7). All the new transects fall into areas of marsh that are dominanted by *Typha angustofolia* (cattail), with scattered patches of *Phargmites.*

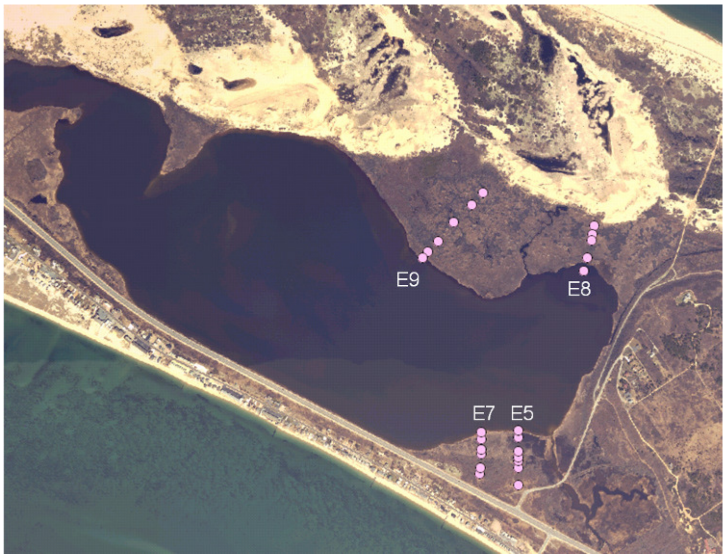

Figure 7. Map showing plots along new transects established in 2008 for long term vegetation monitoring.

Data analysis

Non-metric multidimensional scaling was used to illustrate changes in the composition of the plant community between 2007 and 2008. Analysis of Similarities (ANOSIM) was used to test for significance of these changes (Primer™ ver. 6). In addition, Repeated-measures Analysis of Variance (ANOVA) was used to assess annual changes in *Phragmites* heights, densities, and biomass (all plots pooled).

Results

While minor changes in the cover of non-dominant species occurred between 2007 and 2008 (Table 3), there was no statistically significant change in overall species composition as assessed by ANOSIM (Global R = -0.011; p = 0.69). Figure 8 shows non-metric multidimensional scaling of species raw cover scores where only a minor shift in the scatter of plots is evident.

Table 3. Frequency of occurrence (% of total plots in which taxa occurs) of East Harbor vegetation in 2007 vs. 2008 (Direction of change is given as a + for increase, - for decrease, and nc for no change).

	2007	2008	Change
Aster novi-belgii	8%	8%	nc
Bohmeria cylindrica	5%	5%	nc
Calystegia sepium	0%	5%	+
Decodon verticillatus	3%	0%	-
Erechtites hieracifolia	0%	3%	+
Erechtites hiericifolia	3%	0%	-
Galium trifidum	0%	3%	+
Impatiens capensis	3%	3%	nc
Lemna minor	3%	5%	+
Lysimachia terrestris	0%	3%	+
Lythrum salicaria	11%	8%	-
Onoclea sensibilis	8%	8%	nc
Parthenocissus cinquefolia	5%	0%	-
Phragmites australis	46%	46%	nc
Polygonum arifolium	3%	3%	nc
Rosa palustris	5%	5%	nc
Rumex orbiculatus	5%	8%	+
Sphagnum sp.	3%	3%	nc
Thelypteris palustris	41%	43%	+
Toxicodendron radicans	41%	43%	+
Triadenum virginicum	0%	3%	+
Typha angustifolia	51%	51%	nc

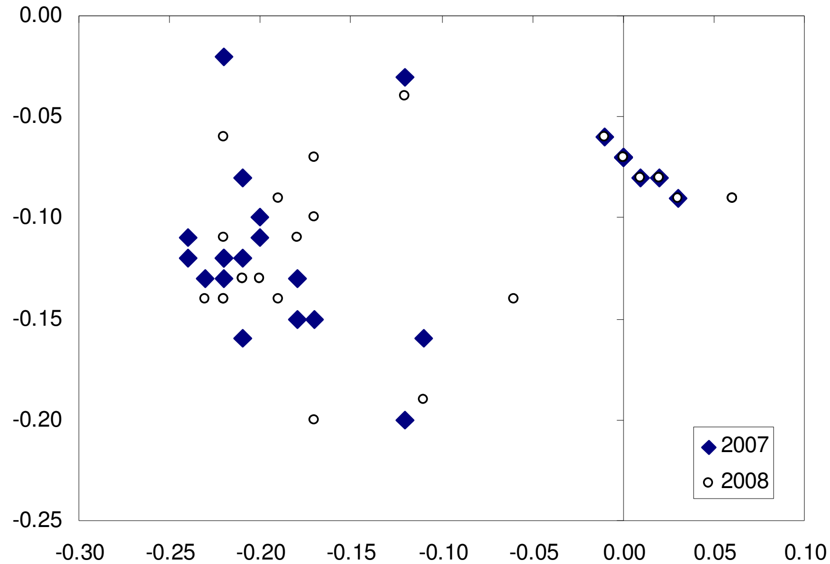

Figure 8. Non-metric multidimensional scaling of summed cover class values of East harbor plant taxa in vegetation plots (August 2006 vs. August 2007).

For the dominant species of emergent vegetation, *Typha* and *Phragmites*, there was relatively little change along the transects (Table 4). In some plots, *Phragmites* cover appears to have increased slightly, but this might be a short-term response to higher amounts of rainfall during this particular summer. The same temporary trend has been observed in Hatches Harbor in wet years, although the overall long –term trend is one of significant decline. In addition, it is obvious that there is decline in many areas outside the plot network. This is conspicuous in aerial photography and is discussed below.

Table 4. *Typha* and *Phragmites* cover scores in August of 2007 and 2008.

Plot	Species	2007	2008	Change	Plot	Species	2007	2008	Change
EH1-005	Typha angustifolia	5	6	1	EH1-085	Phragmites australis	3	3	0
EH1-025	Typha angustifolia	5	6	1	EH3-060	Phragmites australis	7	7	0
EH1-045	Typha angustifolia	5	6	1	EH3-080	Phragmites australis	3	4	1
EH1-065	Typha angustifolia	6	5	-1	EH3-100	Phragmites australis	4	6	2
EH1-085	Typha angustifolia	6	3	-3	EH3-120	Phragmites australis	7	7	0
EH1A-005	Typha angustifolia	4	5	1	EH3-140	Phragmites australis	7	7	0
EH1A-025	Typha angustifolia	4	6	2	EH3-160	Phragmites australis	7	7	0
EH1A-045	Typha angustifolia	4	6	2	EH3-180	Phragmites australis	7	7	0
EH1A-065	Typha angustifolia	5	6	1	EH3-200	Phragmites australis	7	7	0
EH1A-085	Typha angustifolia	6	7	1	EH3-220	Phragmites australis	6	7	1
EH2-005	Typha angustifolia	3	4	1	EH3-240	Phragmites australis	4	4	0
EH2-025	Typha angustifolia	6	6	0	EH4-000	Phragmites australis	7	7	0
EH2-045	Typha angustifolia	5	6	1	EH4-020	Phragmites australis	7	7	0
EH2-065	Typha angustifolia	6	6	0	EH4-040	Phragmites australis	0	0	0
EH2-085	Typha angustifolia	5	5	0	EH4-060	Phragmites australis	0	0	0
EH2-105	Typha angustifolia	5	5	0	EH4-080	Phragmites australis	0	0	0
EH2-125	Typha angustifolia	5	5	0	EH4-100	Phragmites australis	5	7	2
EH2-145	Typha angustifolia	7	7	0	EH4-120	Phragmites australis	6	7	1
EH3-240	Typha angustifolia	3	4	1	EH4-140	Phragmites australis	3	5	2
					EH4-160	Phragmites australis	5	7	2

Phragmites biomass (calculated from maximum stem height measurements and stem density counts), apparently increased between 2007 and 2008 in many plots (Figure 9). This "recovery" from the year prior may be due to higher rainfall in 2008 compared with 2007 (see Table 2 above). However, it may also be due simply to relatively minute changes in cover that are somewhat exaggerated by the small size of 1-m^2 plots. Compared with the 2003, biomass in 2008 was lower in almost every plot. Overall (all plots pooled), there was no statistically significant change in biomass during the last three years along the transects. From a longer term perspective, *Phragmites* has declined significantly over the last 6 years, with values being almost halved since 2003 (Figure 10).

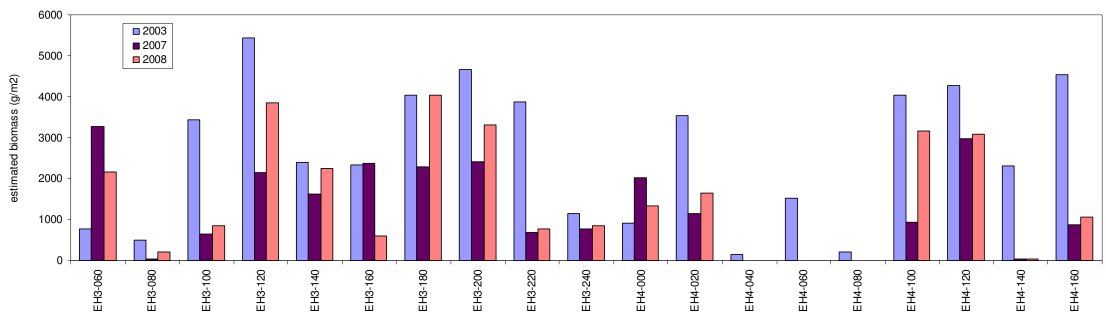

Figure 9. *Phragmites* biomass along transects EH3 and EH4 by individual plots and year (note: there are no error bars as only one biomass value can be calculated for each plot).

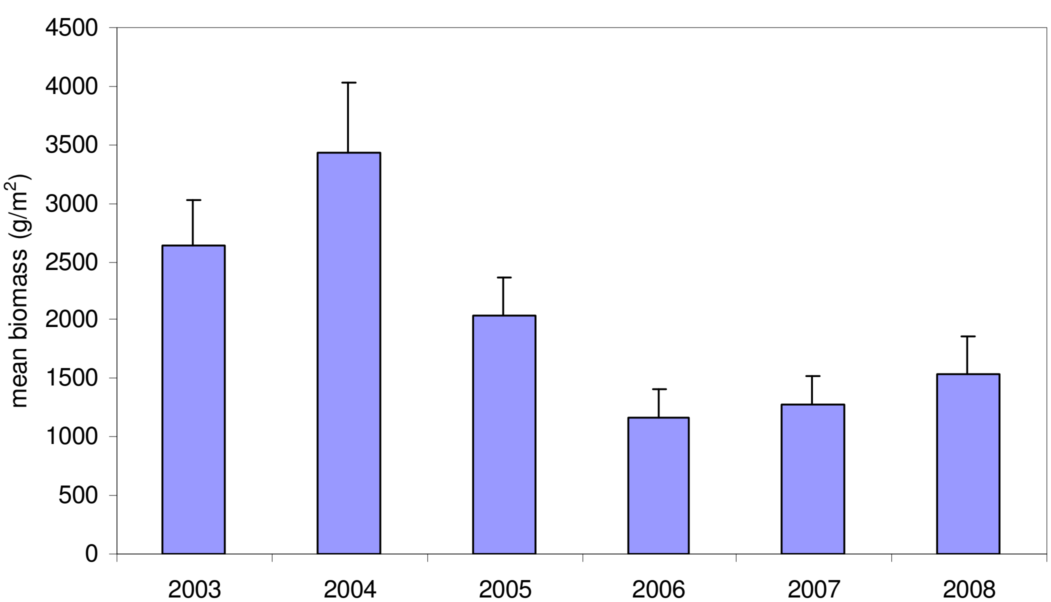

Figure 10. *Phragmites* mean biomass (all plots pooled) by year (error bars are standard error of the mean).

Erratum: *Phragmites* biomass values for plot EH4-140 were incorrect in previous reports (4 times too large due to error in recording quadrat size) (Portnoy et al. 2005, 2006, 2008).

Salt-induced stress and mortality in *Phragmites* is extremely heterogeneous over a broad area in Moon Pond and this is why the permanent ground-level plots do not show some of the changes that are obvious in aerial photography (Figure 11). In general, *Phragmites* continues to decline in the lower elevation areas of Moon Pond and in areas adjacent to where salt has already killed *Phragmites*. Thus, changes continue to occur, even without any corresponding alterations in tidal flow. We suspect that this is because the degradation of *Phragmites* and *Typha* from salinity stress can alter the physical properties of the marsh such that even more degradation is facilitated. When *Phragmites* disappears, water is able to move more freely across the marsh surface and may penetrate further into it. In addition, without the shading effect of standing vegetation, there is more evaporation, which leads to higher porewater salinities – all encourage further decline of *Phragmites* and any freshwater wetland species.

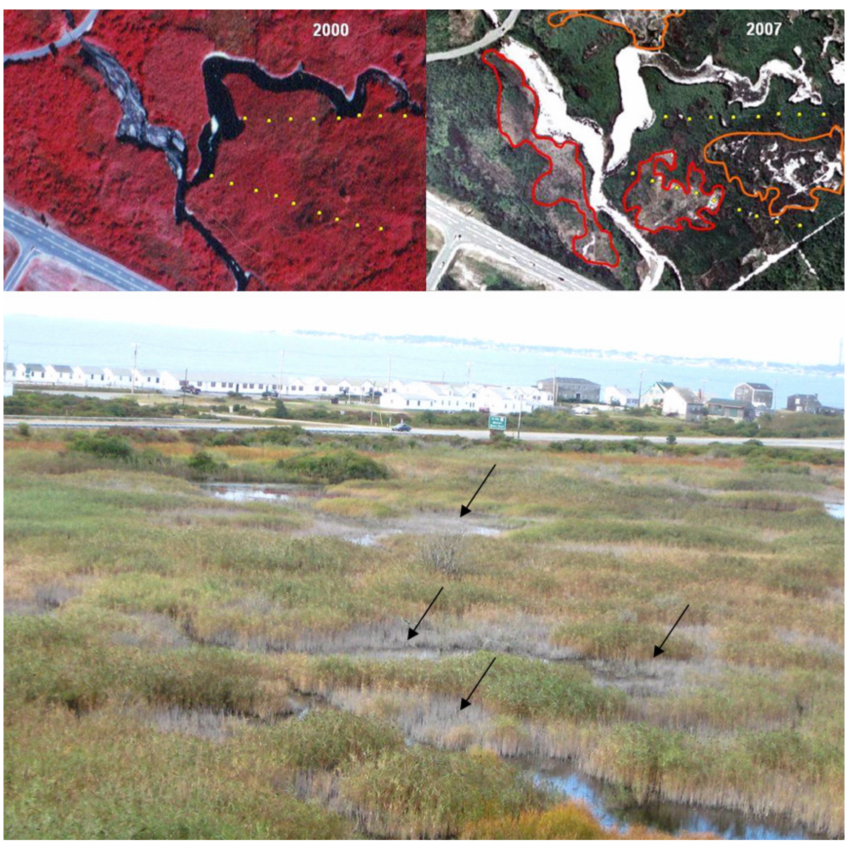

Figure 11. Photographs showing 1) the relationship between plot locations and areas of *Phragmites* (red polygons) or *Typha* (orange polygons) dieback due to salinity and increased tidal flooding (above photos)

and 2) low level views of Moon Pond with open areas emerging as a result of *Phragmites* decline (arrows).

Native salt marsh plants

A variety of native halophytes became established in East Harbor as a direct result of seeding and plantings in past years (see Portnoy et al. 2008). These populations are now producing prodigious amounts of their own seed – some of which is dispersing to new locations and germinating. Moreover, vegetative growth in previously established stands has been rapid and there are now very lush, thick stands of *Spartina alterniflora* and *Salicornia maritima* in different parts of the system that began as just a few small plants (Figure 12).

Figure 12. *Salicornia maritima* (a native salt marsh forb) amidst dead *Phragmites* stems in an area that was never actively seeded.

Porewater salinities

It is important to remember that the porewater salinity data represent a single sampling event. In reality, salinity may fluctuate substantially over the course of a single growing season. Notwithstanding, the spatial gradients in salinity remain similar to past years following the permanent opening of the culvert in 2002, with values decreasing sharply near the upland borders and with EH3&4 transects (Moon Pond) having much higher salinities than EH1&2 (Table 5). In general, these snapshots of salinities show that while the system remains salty, there may be considerable year-to-year fluctuation in porewater conditions. Because these data are a one-time sampling event, it is impossible to know whether how well these values reflect long-term conditions. Salinity dataloggers are needed to elucidate the true nature of salinity dynamics over long periods of time and how well instantaneous measures reflect overall salinity regimes.

Table 5. Porewater salinities in selected plots along the Moon Pond transects (2003-2008).

	2003	2004	2005	2006	2007	2008
EH1-005	4	2	5	0	2	0
EH1-045	5	2	4	2	2	0
EH1-085	5	2	5	0	2	1
EH1A-005	4	2	4	0	3	2
EH1A-045	10	2	8	8	4	2
EH1A-085	10	1	9	10	6	3
EH2-025	2	0	4	0	1	3
EH2-065	2	0	4	0	2	2
EH2-105	2	2	4	7	2	1
EH2-145	3	2	7	7	8	2
EH3-060	dry	15	dry	dry	dry	dry
EH3-100	25	22	23	20	20	26
EH3-140	24	13	22	14	-	22
EH3-180	23	15	20	12	10	14
EH3-220	21	8	14	2	5	3
EH4-000	25	20	-	-	25	28
EH4-040	33	32	37	34	35	34
EH4-080	32	32	34	26	32	33
EH4-120	30	20	30	15	20	20
EH4-160	29	11	24	12	14	14
mean-EH1/2	4.7	1.5	5.4	3.4	3.2	1.6
mean-EH3/4	26.9	18.8	25.5	16.9	20.1	21.6

Submerged Aquatic Vegetation

All previous monitoring results and methods for SAV monitoring can be found in Portnoy et al. (2006). On average, the cover of *R. maritima* (widgeongrass) increased by over 25% along the deep transects in the lagoon between 2007 and 2008 (Table 6). This increase was mainly due to the large changes at sites 7 and 8. Outside the transects, large, vigorous beds of *R. maritima* grew along sections of the norther shore of the lagoon (see Figure 13 below). *Zostera marina* (eelgrass) was not recorded along any of the transects – the first time that this species has not been recorded at any site, although it was observed in other locations throughout the lagoon in 2008. In general, however, the abundance of *Z. marina* remains very low, despite the very large population of this species in the shallow waters of Cape Cod Bay in and around the inflow pipe.

Table 6. Percent cover of submerged aquatic vegetation by transect in East Harbor in 2004-2008.

		R. maritima				*Z. marina*			
	Transect	Sep 04	Sep 05	Sep 07	Sep 08	Sep 04	Sep 05	Sep 07	Sep 08
shallow	8	10%	16%	16%	48%	2%	2%	0%	0%
	6	22%	64%	98%	4%	0%	0%	0%	0%
	1	34%	68%	0%	0%	0%	0%	0%	0%
	4	6%	42%	58%	56%	0%	0%	0%	0%
	7	26%	74%	46%	98%	0%	0%	2%	0%
deep	8	4%	16%	20%	78%	0%	2%	0%	0%
	6	2%	64%	90%	96%	0%	0%	0%	0%
	1	20%	52%	4%	0%	0%	0%	0%	0%
	4	8%	38%	44%	64%	0%	0%	0%	0%
	7	6%	50%	48%	94%	0%	2%	0%	0%
	mean shallow	22.0%	62.0%	43.6%	41.2%	0.4%	0.4%	0.4%	0.0%
	mean deep	9.0%	51.0%	41.2%	66.4%	0.0%	0.8%	0.0%	0.0%
	mean total	14%	48%	42%	54%	0%	1%	0%	0%

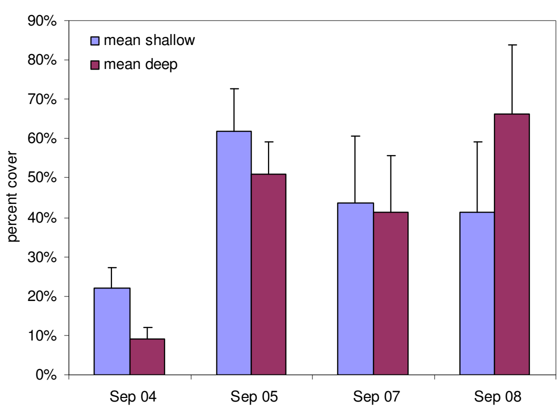

Figure 13. Percent cover values (determined by single point intercepts along transects) of shallow vs. deep transects (error bars are standard errors) and vigorous bed of *R. maritima* (right-side photo) on the north side of the lagoon (July 2008).

Macroalgae

Systematic monitoring has not been developed for macroalgae in East Harbor. The main difficulty is that the spatial distribution of macroalgae is highly variable since it can break away from the substrate to which it is attached in the germling stage and drift around in the water. Anecdotal observations on macroalgae indicated that while a large amount grew in the system in 2008, biomass was far less than in 2006 when an enormous bloom occurred. Nonetheless, wind-driven accumulation of macroalgae is still causing problems, including shellfish (primarily *Mya* *arenaria*, soft-shelled clams) dieoffs (Figure 14). *Ulva intestinalis* and to a slightly lesser extent *Cladophora* spp. still appear to comprise the bulk of macroalgae in the system. There is, however, a distinct pattern of seasonal succession with the red algae *Polysiphonia* and *Neosiphonia harveyi* increasing toward the end of the summer and into the fall.

In 2008, several important observations were made with regard to macroalgal growth and distribution in East Harbor:

1. Macroalgae originates on hard substrate in the system, including pebbles, stones, rip rap, peat, relic plant roots, and mollusc shell fragments

2. Macroalgae has no particular affinity for seagrass as a substrate to grow on. The association of macroalgae with seagrass is purely physical in that detached and drifting algae often becomes entangled with it and subsequently grows in that location, often to the point that it smothers the seagrass and causes its decline.

3. The distribution of macroalgae throughout the system is highly influenced by strong wind events

Figure 14. Macroalgae accumulation (August 2008) (left) and soft-shell clam mortality in an area that was previously blanketed by macroalgae (Sept 2008).

Gastropod mollusc study

Previous years data on gastropod mollusc responses to East Harbor restoration revealed a lack of two important herbivore/detritivores in the main lagoon. These are *Littorina littorea* (common periwinkle) and *Ilyanssa obsoleta* (Eastern mud snail). Both have been found to be very important consumers of live and dead macroalgae and microalage. In 2008, the absence of *L. littorea* from the main lagoon was investigated and grazing effects studied. The results were synthesized into a paper submitted for publication in Environmental Management. Below is the abstract (summary) for this work and two figures that illustrate the results (Figures 15, 16):

East Harbor (Truro, Massachusetts, U.S.A.) is a tidally-restricted salt marsh lagoon that has undergone partial restoration since 2002. After re-introducing seawater to the system following nearly 140 years of impoundment, remarkable transformations in plant and animal communities have occurred. While a host of marine fish, crustaceans, and benthic invertebrates have become established throughout the system, an important herbivore, *Littorina littorea* (common periwinkle), has not. Although having successfully colonized the main tidal creek that now connects the system with Cape Cod Bay, this gastropod mollusc is absent throughout the open lagoon where in the past several years macroalgae (particularly *Ulva intestinalis*) has proliferated to nuisance levels. Grazing experiments with *L. littorea* introduced from the creek suggest that this species could significantly reduce the extent of macroalgae biomass there. The inability of this organism to colonize the lagoon may be related to temperature regime. Thermal tolerance bioassays using individuals from the tidal creek suggest a lethal high-temperature limit of ~27-30°C and data from in situ temperature loggers show that this threshold is exceeded in many parts of the lagoon during July-August. Moreover, there is a well-defined spatial pattern in temperature regime that corresponds with the population distribution of *L. littorea*. Further enhancement of tidal exchange could lower water temperatures throughout East Harbor, which might allow this species to greatly expand its range in the system and limit macroalgae through herbivory. This study further suggests that *L. littorea* could be used as an indicator species during tidal restoration as well as highlighting the importance of restoring temperature regimes for the functional recovery of hydrologically-impaired systems.

Figure 15. Photographs showing an example of macroalgae (*U. intestinalis*) control in a cage with periwinkles (left; low density treatment) vs. without periwinkles (right; control treatment) (site 1; June).

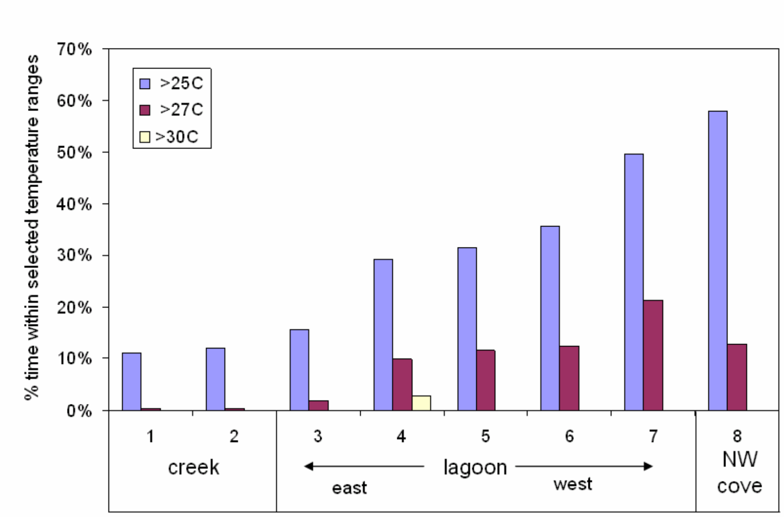

Figure 16. Percentages of time that water temperatures fell within selected ranges by location (Sites 1 and 2 are in tidal creek, sites 3-7 in main lagoon, site 8 in the NW cove).

Enhancement of saltwater influence by berm perforation in Moon Pond (East Harbor)

With the help of the Cape Cod Mosquito Control Project (CCMCP), several openings were created in existing earthen berms within the Moon Pond area of East Harbor. Since 2002, when partial tidal restoration began, vegetation in this part of the system has exhibited very positive changes. There has been a dramatic reduction in non-native species that had invaded the floodplain there, corresponding with a rapid expansion in native salt marsh plants. However, the extent of influence of salt water flooding in Moon Pond is constrained by numerous berms that prevent water from flowing into certain areas (see Figure 16 below).

Using the expertise and machinery of CCMCP, two of the berms were perforated by making small cuts in them (approximately 1-2 m wide), l thereby allowing surface water to flow through (Figure 17). It is expected that this will increase the salinity of areas behind the berms - resulting initially in cattail mortality and *Phragmites* decline. Because there are vigorous stands of native salt marsh grasses adjacent to these areas, colonization by species such as *Spartina alterniflora* (cordgrass), *Spartina patens* (salt marsh hay), and *Salicornia species* (glassworts) should occur shortly thereafter. It is expected that this activity would result in the restoration of roughly 2.5 acres of wetland.

Figure 17. Berm cutting (Dec 17) (left) and map of Moon Pond area (right) with sites of berm perforation (yellow push-pin icons). The polygons delineate the areas that would be affected.

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IV. SHELLFISH

Jodie Wennemer and Rachel Thiet

Introduction

Bivalves, often the most abundant suspension feeders within an estuary, are an integral part of coastal ecosystems, providing several functions necessary for the overall health of the habitat. Bivalves are primarily dependent upon phytoplankton as a food source, although organic detritus and microphytobenthos may also provide food energy in some systems (Prins et al., 1997). Suspension feeding bivalves remove the suspended matter from the water column and deposit fecal matter, which provides food energy for other species within the system (Peterson and Heck, 1999). The increased nutrient level in the water column has been shown to support seagrass populations (Peterson and Heck, 1999), such as the eelgrass (*Zostera marina*) and widgeongrass (*Ruppia maritima*). Monitoring of the molluscan communities within East Harbor continued during the 2008 summer field season.

Methods

East Harbor estuary is comprised of the 350-acre East Harbor Lagoon and 370 acres of emergent wetland in Moon Pond, Salt Meadow, and the fringing marsh around the main lagoon. We sampled three distinct areas of East Harbor Lagoon in 2008: Moon Pond, the Main Lagoon, and the Northwest Cove. Sixty-five stratified random sampling points were established using ArcGIS 9.2 software: 20 in Moon Pond, 15 in the Northwest Cove, and 30 in the Main Lagoon. A stratified random sampling method was used because salinity varies among these three areas.

Molluscan communities were sampled at each sampling point using a benthic core method; samples (20cm depth) were taken using a 10” PVC pipe designed for benthic coring. Each of the five cores at each sample point was sieved through a 1mm mesh and any molluscs found were identified to species and measured (mm) using a stainless field caliper. The sieved material from each core sample was searched thoroughly for two minutes to ensure unbiased detection of individual molluscs.

Pearson’s product moment correlations were used to determine if relationships existed between species richness and salinity, submerged aquatic vegetation (SAV) density, and sediment particle size distribution. Pearson’s product moment correlations were also used to determine if relationships exist between mollusc densities and salinity, submerged aquatic vegetation (SAV) density, and sediment particle size distribution.

Results

Species richness

In total, 11 species of molluscs were detected in East Harbor during the 2008 summer field season. As in 2007, species richness was highest in Moon Pond and lowest in the Northwest Cove (Table 7). Species richness was positively correlated with salinity (r (63) = 0.23, $\alpha = 0.05$) and with very coarse sand (>1mm) (r (63) = 0.23, $\alpha = 0.05$). Only soft shell clams (*Mya arenaria*) and the fragile bubble shell (Order *Cephalispidea*) were present in all three areas. The fragile bubble shell was the most abundant species found in the system, with the Northwest Cove containing the highest densities.

Size and distribution of individuals

Nearly 30% of soft shell clams (*Mya arenaria*) sampled within Moon Pond, and 60% of those sampled in the Northwest Cove, were of harvestable size (Table 8). No harvestable soft shell clams were detected in the Main Lagoon. The northern quahog (*Mercenaria mercenaria*) was not detected at harvestable size anywhere in the system.

The majority of species were found in highest densities in Moon Pond: northern moon snail (*Euspira heros*), amethyst gem clam (*Gemma gemma*), northern quahog (*Mercenaria mercenaria*), mud snail (*Ilyanassa obsoleta*), dwarf tellins (*Tellina agilis*), and false angel wing (*Petricola pholadiformis*) (Table 8). The soft shell clam (*Mya arenaria*), little surf clam (*Mulinia lateralis*), and Obsole macoma (*Macoma baltica*) were found in highest densities in the Main Lagoon (Table 8). Only the fragile bubble shell (Order *cephalaspidea*) reached its peak denisties in the Northwest Cove (Table 8). Mollusc density was positively correlated with submerged aquatic vegetation density (r (65) = 0.35, $\alpha = 0.05$).

Discussion

Our results demonstrate that molluscs continue to colonize and thrive in East Harbor, particularly in Moon Pond, where there is a direct connection to Cape Cod Bay through a four-foot diameter culvert. The soft shell clam (*Mya arenaria*) and the northern quahog (*Mercenaria mercenaria*), two species of interest to the shell fishing industry, were present in East Harbor. In the Northwest Cove, the majority (60%) of soft shell clams were of harvestable size. The abundance of large soft shell clams in this area of East Harbor is likely due to high organic detritus levels and the soft, silty sediment. No harvestable quahogs were detected, but their presence in Moon Pond indicates the potential for a harvestable population in the future. Although harvestable soft shell clams were found, opening East Harbor to public shellfish harvest depends upon the results of fecal coliform monitoring by the Massachusetts Division of Marine Fisheries and a decision by both DMF and the Truro Shellfish Constable, in consultation with Cape Cod National Seashore.

The dramatic increase in the abundance of the fragile bubble shell (Order *Cephalaspidea*) this year may be related to the algal blooms that have occurred in East Harbor, as algae are a primary food source for the bubble shell. Similarly, there was a late-season population explosion of mud snail (*Ilyanasa obsoleta*), which was observed but not quantified in this study. This may be related to food source availability although the population of *Ilyanassa* in Moon Pond was artificially augmented by NPS staff (by many hundreds of individuals) during 2008.

Although the number of species detected in East Harbor has decreased since 2005 (16 species detected in 2005, 12 species detected in 2007), the 2008 density and distribution indicate a healthy and diverse molluscan population. Other species that were observed in the system, but were not present in the plots include *Littorina littorea* (common periwinkle) and *Limulus polyphemus* (Atlantic horseshoe crab).

Table 7: Mollusc densities (individuals m^{-2}) in East Harbor by area sampled in July-August 2008. Five 10-cm cores were collected at each sample point in each area (*n* = number of sample points); thus, unit area is extrapolated up to 1 m^2 (total individuals sampled * 2 / *n*).

Species	**Moon Pond** (*n*=20)	**Main Lagoon** (*n*=50)	**Northwest Cove** (*n*=15)
Euspira heros	0.1	0	0
Gemma gemma	10.3	0.06	0
Macoma balthica	0	0.4	0
Mercenaria mercenaria	2.8	0	0
Ilyanassa obsoleta	0.3	0	0
Mulinia lateralis	0.1	0.46	0
Mya arenaria	11.6	13.13	3.6
Order *Cephalaspidea*	0.1	24.13	28.67
Mytilus edulis	0	0.07	0
Petricola pholadiformis	0.1	0	0
Tellina agilis	4.7	0.26	0

Table 8: Average size of mullscs (mm) in the three subsections of East Harbor in July-August 2008. Five 10-cm cores were collected at each sample point in each area (*n* = number of sample points). Data are mean (± standard error); where no SE is given, only one individual was found.

Species	**Moon Pond** (*n*=20)	**Main Lagoon** (*n*=50)	**Northwest Cove** (*n*=15)
Euspira heros	42.0	--	--
Gemma gemma	2.02 (± 0.07)	1.0	--
Macoma balthica	--	22.17 (± 3.13)	--
Mercenaria mercenaria	10.50 (± 1.60)	--	--
Ilyanassa obsoleta	25.0 (± 3.46)	--	--
Mulinia lateralis	6.0	9.71 (± 0.75)	--
Mya arenaria	30.3 (± 2.54)	29.62 (± 0.51)	51.74 (± 0.94)
Mytilus edulis	--	0.8	--
Order *Cephalaspidea*	9.0	6.02 (± 0.95)	5.3 (± 0.14)
Petricola Pholadiformis	6.0	--	--
Tellina agilis	7.81 (± 0.32)	10.25 (± 0.85)	--

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V. NEKTON (FISH AND DECAPOD CRUSTACEANS)

Megan Tyrrell

Introduction

CACO has been monitoring the nekton community in the East Harbor system since 2003. Nekton are expected to be particularly sensitive indicators of changing environmental conditions because of their high degree of mobility, especially as compared to other estuarine biota. CACO monitors the species composition, density and size distributions of nekton in combination with water temperature, depth, salinity, dissolved oxygen, sediments and vegetation at each sampling location to examine their relationship with nekton community structure. In addition, tracking these environmental factors allow natural resource managers and scientists to examine how environmental conditions vary over time. Below is a brief synthesis of the nekton monitoring data from the East Harbor lagoon and Moon Pond creek system with a focus on data from 2008.

Methods

As this was the sixth year of nekton monitoring in the East Harbor system, sampling design, methods and equipment were similar to those of previous years. The reader is referred to previous East Harbor Annual reports (Portnoy et al. 2005, 2006, 2008) as well as the CACO nekton monitoring protocol (Raposa and Roman, 2001) for a detailed description of sampling methods. Unless noted otherwise, all methods in 2008 followed the Raposa and Roman (2008) protocol.

Sample Design

Nekton were sampled at randomly selected stations in East Harbor Lagoon and Moon Pond in July and September 2008. Using GPS and aerial photographs as a navigation guide, the September sampling took place in the same location as the July sampling. For throw traps, 28 of the target 30 locations were sampled in East Harbor lagoon and all thirty sampling locations were utilized in Moon Pond. For the seining, all four or the target locations were sampled in East Harbor and the sole Moon Pond seine net site was also sampled. The seine data is only used for reporting species composition and richness.

Data Analysis

Species richness, average density (from throw traps), and the relative abundance of fish and crustaceans were calculated for Moon Pond and East Harbor lagoon. As in 2005 and 2007, when samples were collected in both mid and late summer, the data were pooled over both sampling dates for the purposes of this report. A comprehensive review of the nekton monitoring data is planned for the spring of 2009. A variety of analysis methods, including multivariate statistics, will be employed to examine the efficacy of the nekton and associated environmental data for assessing long term trends as well as tracking system response to remediation of tidal restrictions.

Results and Discussion

Species composition and richness (seines and throw traps)

Prior to the partial restoration in 2002, the only nekton species in East Harbor were Asian carp, white perch, alewife and the American eel (Hartel *et al.* 2003; Mather 2003). The total number of species recorded from the combination of the throw traps and seines in 2008, was eleven in the lagoon and seventeen in Moon Pond (Table 9). Common estuarine inhabitants such as the mummichog, *Fundulus heteroclitus*, and Atlantic silversides, *Menidia menidia*, were recorded in 2008, which was consistent with previous years. These species have wide distributions correlating with their broad tolerance for varying environmental conditions, especially salinity. However in 2008, two species that are affiliated with marine rather than brackish conditions were recorded in Moon Pond, *Tautogolabrus sp.* and *Pseudopleuronectes americanus*, Winter flounder. The presence of these fishes with stenohaline (restricted salinity) tolerances means that conditions in Moon Pond are closely approximating those of natural coastal systems.

Table 9: Nekton species occurrence from seines and throw traps in East Harbor, Moon Pond and Salt Meadow 2003-2008.

	East Harbor Lagoon						Moon Pond						Salt Meadow				
COMMON NAME	2003	2004	2005	2006	2007	2008	2003	2004	2005	2006	2007	2008	2003	2004	2005	2006	2007
American eel	X	X	X	X	X	X	X				X	X		no data	X		X
Atlantic mud crab											X						
Atlantic silverside	X	X	X	X	X	X	X	X	X	X	X	X					
Brown bullhead													X		X	X	X
Black fingered mud crab												X					
Cunner												X					
Four-spine stickleback		X	X	X	X	X					X	X			X	X	X
Golden Shiner													X		X		X
Green crab		X	X	X		X	X	X	X	X	X	X					
Lady crab												X					
Longnose spider crab									X								
Longwrist hermit crab											X	X					
Mummichog		X	X	X	X	X	X	X	X	X	X	X	X			X	X
Nine-spine stickleback			X	X		X	X		X			X			X	X	
Pipe fish		X	X	X	X	X		X		X	X	X					
Portly spider crab											X						
Sand shrimp	X	X	X		X	X		X	X	X	X	X					
Say mud crab											X	X					
Shore shrimp	X	X	X	X	X	X	X	X	X	X	X	X					
Spider crab species								X				X					
Striped killifish				X													
Three-spine stickleback				X		X											
White perch	X	X	X	X	X				X			X	X			X	X
Winter flounder	X		X			X			X	X		X					
Total number of species	**6**	**9**	**11**	**11**	**8**	**11**	**6**	**7**	**10**	**7**	**12**	**17**	**4**		**5**	**5**	**6**

East Harbor Lagoon

The majority of individuals captured in the throw traps in 2008 were fishes, with the relative abundance of fish (87%) versus crustaceans (13%) similar to the previous year (Figure 18). Generally, the relative abundance of species in 2008 resembled the 2006 community composition more closely than the 2007 community (Table 10). For example, the relative abundance of mummichogs in 2008 was ~71%, in 2008 which is similar to the levels from 2006. There had been a steadily increasing proportion of this species from 2004-2006 but the 2007 levels were anomalously low. For other relatively common species such as four spine sticklebacks, sand shrimp and Atlantic silversides, the 2008 proportions were more similar to the community as observed in 2006 than the sampling that took place in 2007. Similarly, the species diversity, as calculated using the Shannon-Weiner index, was slightly lower in 2008 than in the previous years, and was most similar to the diversity in 2006 (Figure 19).

For East Harbor lagoon, higher densities are usually observed in the early summer sampling which takes place at the end of June through mid-July. In 2007, the early summer sampling was approximately two weeks earlier than in 2006 and 2008, which may have contributed to the similarities between 2006 and 2008 relative abundances as compared to the values from 2007. The timing of late summer sampling differed by a week between 2007 and 2008, while in 2006, the late summer sampling was almost three weeks earlier than in 2008. However, only 69 individuals were caught in late summer sampling in 2008, so the effect of any seasonal distribution shifts had a proportionately smaller effect on the overall density and relative abundance results as compared to the early sampling period.

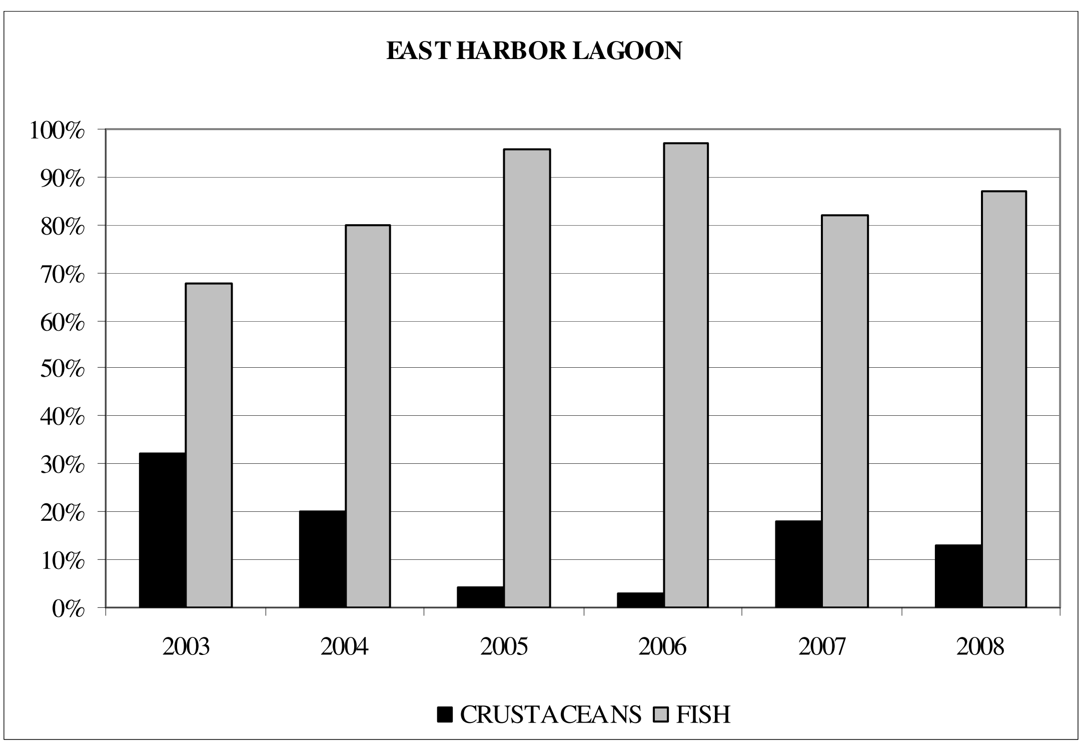

Figure 18: Relative abundance of fish versus crustaceans in nekton monitoring at East Harbor lagoon 2003-2008.

Table 10: Relative abundance of nekton species in East Harbor 2003-2008.

	East Harbor Lagoon					
	2003	2004	2005	2006	2007	2008
CRUSTACEANS	32.41%	20.28%	4.13%	2.95%	18.02%	12.88%
FISH	67.59%	79.72%	95.87%	97.05%	81.98%	87.12%
American eel	0.00%	0.13%	0.32%	0.10%	0.24%	0.66%
Four-spine stickleback	0.00%	18.90%	10.96%	4.53%	13.56%	3.98%
Green crab	0.00%	0.13%	0.04%	0.00%	0.00%	0.27%
Sand shrimp	0.69%	1.00%	0.83%	1.38%	13.73%	1.06%
Mummichog	0.00%	49.56%	53.89%	75.69%	21.05%	70.78%
Striped killifish	0.00%	0.00%	0.00%	0.10%	0.00%	0.00%
Three-spine stickleback	0.00%	0.00%	0.00%	0.10%	0.00%	0.27%
Longnose spider crab	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Spider crab species	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Atlantic silverside	44.83%	9.89%	25.62%	15.94%	46.92%	11.42%
White perch	19.31%	0.38%	4.49%	0.39%	0.21%	0.00%
Shore shrimp	31.72%	19.15%	3.26%	1.57%	4.29%	11.55%
Winter flounder	0.00%	0.00%	0.12%	0.00%	0.00%	0.00%
Nine-spine stickleback	0.00%	0.00%	0.24%	0.10%	0.00%	0.00%
Pipe fish	3.45%	0.88%	0.24%	0.10%	0.00%	0.00%
Unknown crab species	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

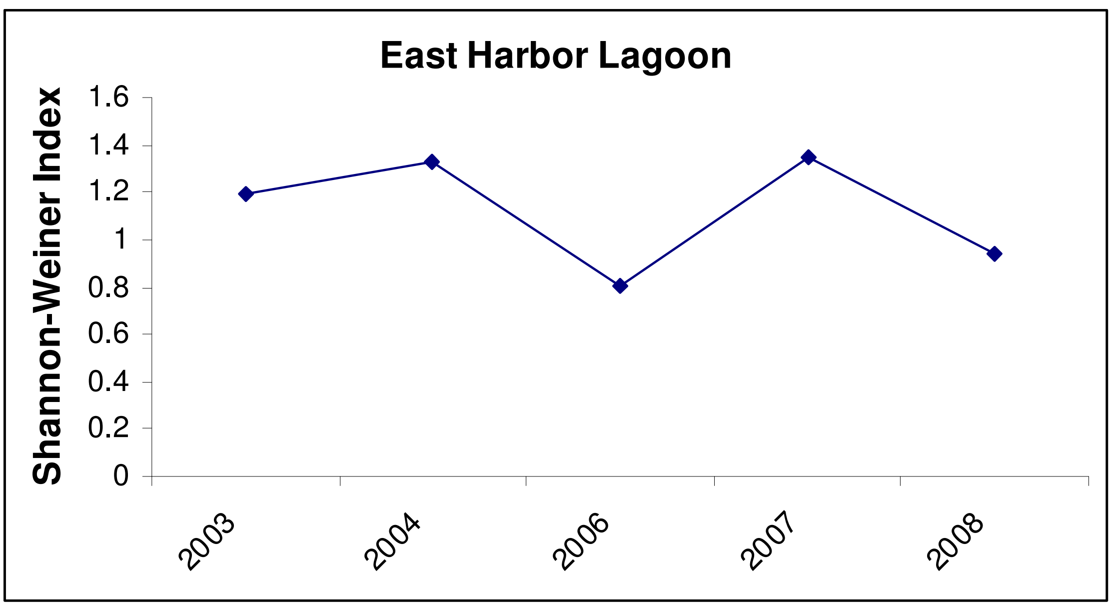

Figure 19: Species diversity from throw trap sampling in East Harbor lagoon as measured by the Shannon-Weiner index.

The density of nekton in East Harbor in 2008 was slightly lower than that of the previous 4 years (Table 11), which may be due to the comparatively late sampling date (September 18) as compared to 2006 and 2007. The variability in crustacean density from 2003-2008 is much lower than that of fish density, which is likely partially due to the higher densities of fish captured in the throw traps. The densities of four spine sticklebacks, sand shrimp, mummichogs and Atlantic silversides were relatively low in 2008 as compared to recent years. Four spine sticklebacks and mummichogs had substantially lower densities for the September sampling as compared to the July sampling.

Table 11: Density of nekton as obtained from 1 m sq. throw traps in East Harbor lagoon, 2003-2008

	EAST HARBOR LAGOON											
	2003		2004		2005		2006		2007		2008	
n	*19*		*30*		*42*		*29*		*30*		*48*	
	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV
TOTAL NEKTON	7.63	13.56	27.41	48.58	18.43	34.35	35.03	34.14	20.15	4.97	15.10	21.80
CRUSTACEANS	2.47	7.16	5.52	19.14	2.17	7.90	1.03	2.15	3.88	2.95	1.67	4.68
FISH	5.16	10.15	21.90	38.19	16.26	31.69	34.00	33.51	16.27	2.03	13.44	21.20
American eel	0.00	0.00	0.03	0.18	0.12	0.40	0.03	0.19	0.05	0.02	0.10	0.37
Four-spine stickleback	0.00	0.00	5.21	15.54	4.21	10.17	1.59	3.51	2.30	2.83	0.63	1.55
Green crab	0.00	0.00	0.03	0.18	0.02	0.15	0.00	0.00	0.00	0.00	0.04	0.29
Sand shrimp	0.05	0.23	0.21	0.83	0.45	1.50	0.48	1.21	3.15	3.79	0.08	1.41
Mummichog	0.00	0.00	13.59	35.61	10.19	28.52	26.52	31.81	3.70	3.35	10.99	24.08
Striped killifish	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.19	0.00	0.00	0.00	0.00
Three-spine stickleback	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.19	0.00	0.00	0.04	0.29
Atlantic silverside	3.42	8.73	2.72	4.60	0.60	1.86	5.59	13.43	10.17	8.11	1.69	4.23
White perch	1.47	3.50	0.10	0.31	0.88	2.09	0.14	0.44	0.05	0.07	0.00	0.00
Shore shrimp	2.42	7.17	5.28	18.86	1.69	6.44	0.55	1.45	0.73	0.85	1.54	4.53
Winter flounder	0.00	0.00	0.00	0.00	0.07	0.34	0.00	0.00	0.00	0.00	0.00	0.00
Nine-spine stickleback	0.00	0.00	0.00	0.00	0.07	0.26	0.03	0.19	0.00	0.00	0.00	0.00
Pipe fish	0.26	1.15	0.24	0.94	0.12	0.33	0.03	0.19	0.00	0.00	0.00	0.00

Moon Pond

The relative abundance of crustaceans to fish is more even in Moon Pond as compared to East Harbor lagoon (Figure 20). 2008 was the first year when fish were more abundant than crustaceans in Moon Pond, whereas fish are by far more abundant in East Harbor lagoon as compared to crustaceans (Figures 18, 20). This result may be due to the comparatively low relative abundance of sand shrimp, *Crangon septemspinosa,* which was substantially lower in 2008 as compared to the previous two years, and was the second lowest proportion of all sampling years (Table 12). This species has generally had high variability in its relative abundance through the six year sampling period. Similarly, Atlantic silversides have had high variability in their relative abundance in Moon Pond from 2003-2008. In 2008, the proportion of this species was almost three times higher than it had ever been in the past. While shore shrimp, *Palaemonetes sp.,* had been generally declining in their relative abundance in Moon Pond from 2003-2006, this trend has subsided and the 2008 level was slightly higher (~35%) than the 2007 proportion (28%). Winter flounder, a species with commercial value, has been encountered in low relative abundance in Moon Pond for three years: 2005, 2006 and 2008. 2008 was the first year that lady crab, *Ovalipes ocellatus*, and cunner, *Tautogolabrus* sp., were encountered in the throw traps. After climbing steadily for three years following the partial mitigation of the tidal restriction to the ocean, the species diversity in Moon Pond has been relatively stable for the past three years (Figure 21). The Shannon-Weiner diversity values, especially in recent years, are higher than those of the adjacent lagoon.

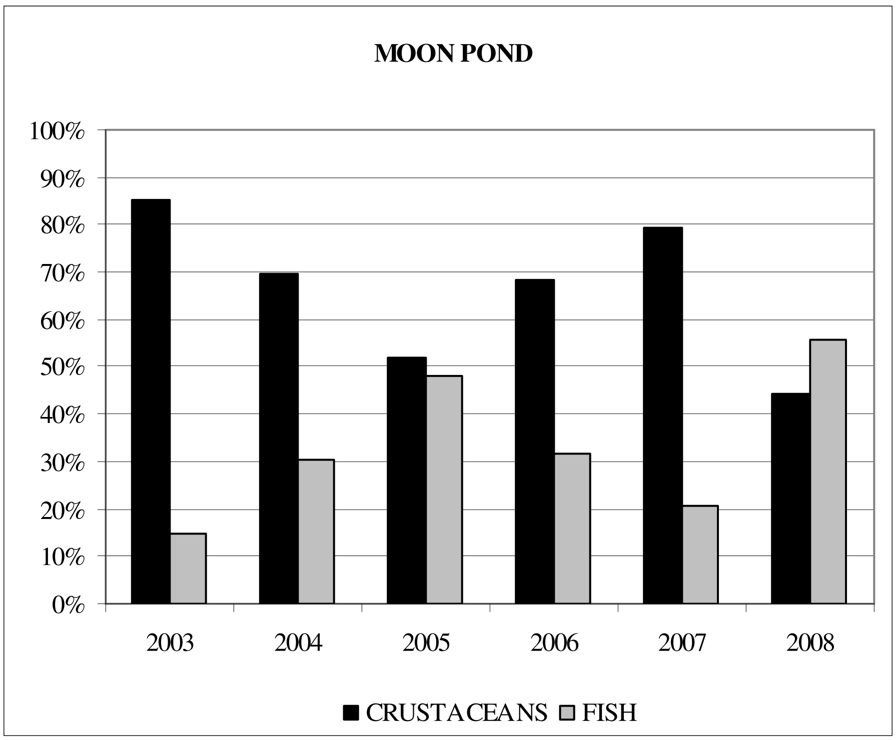

Figure 20: Relative abundance of fish versus crustaceans in nekton monitoring at Moon Pond, a component of the East Harbor ecosystem, 2003-2008.

Table 12: Relative abundance of nekton species in Moon Pond 2003-2008.

	Moon Pond					
	2003	2004	2005	2006	2007	2008
CRUSTACEANS	85.20%	69.62%	51.89%	68.56%	79.32%	44.22%
FISH	14.80%	30.38%	48.11%	31.44%	20.68%	55.78%
American eel	0.36%	0.00%	0.00%	0.00%	0.11%	0.00%
Four-spine stickleback	1.33%	5.41%	8.66%	1.14%	5.37%	0.20%
Green crab	0.18%	1.11%	2.21%	6.61%	2.77%	3.38%
Sand shrimp	0.00%	7.87%	16.31%	48.75%	48.26%	5.22%
Mummichog	9.95%	14.39%	31.34%	16.63%	8.08%	15.35%
Longnose spider crab	0.00%	0.00%	0.09%	0.00%	0.00%	0.00%
Spider crab species	0.00%	0.12%	0.00%	0.00%	0.00%	0.31%
Atlantic silverside	2.30%	10.46%	6.27%	10.93%	6.91%	38.38%
White perch	0.00%	0.00%	0.74%	0.00%	0.00%	0.00%
Shore shrimp	85.02%	60.52%	32.90%	13.21%	27.61%	34.90%
Winter flounder	0.00%	0.00%	0.28%	1.37%	0.00%	1.02%
Nine-spine stickleback	0.85%	0.00%	0.83%	0.00%	0.00%	0.00%
Pipe fish	0.00%	0.12%	0.00%	1.37%	0.20%	0.41%
Unknown crab species	0.00%	0.00%	0.37%	0.00%	0.00%	0.00%
Say mud crab	0.00%	0.00%	0.00%	0.00%	0.29%	0.00%
Portly spider crab	0.00%	0.00%	0.00%	0.00%	0.20%	0.00%
Longwrist hermit crab	0.00%	0.00%	0.00%	0.00%	0.10%	0.00%
Atlantic mud crab	0.00%	0.00%	0.00%	0.00%	0.10%	0.00%
Lady crab	0.00%	0.00%	0.00%	0.00%	0.00%	0.41%
Cunner	0.00%	0.00%	0.00%	0.00%	0.00%	0.41%

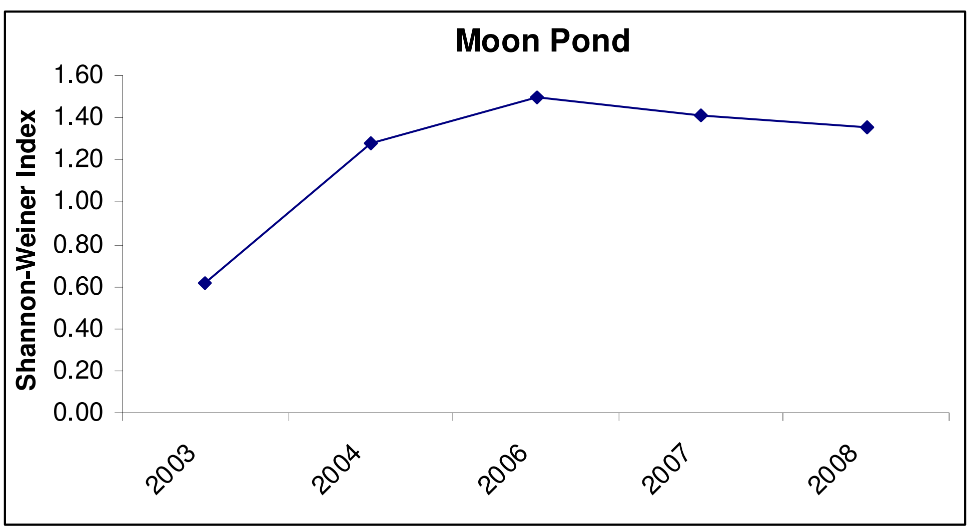

Figure 21: Species diversity from throw trap sampling in Moon Pond as measured by the Shannon-Weiner index.

The density of nekton in Moon Pond in 2008 is the second highest of the whole time series; 2003 had the highest nekton densities overall (Table 13). The density of fish in 2008 was twice as high as 2005, the year with the next closest values. The density of crustaceans has been highly variable over the time series, which was mostly due to high densities of shore shrimp in 2003. In 2008, shore shrimp were again highly abundant while sand shrimp had relatively low densities, especially as compared to the previous 3 years. Spider crabs, *Libinia* sp., were recorded in the throw traps in 2008 albeit in relatively low densities. This is surprising considering they have only been encountered twice before in the Moon Pond throw trap sampling, 2004 and 2007. The density of Atlantic silversides was four times higher in 2008 than the next closest year and winter flounder were also found in higher densities in 2008 than any previous year. As previously mentioned, cunner and lady crabs were encountered for the first time in throw trap sampling; their densities were the same as that of pipefish.

Table 13: Density of nekton as obtained from 1 m sq. throw traps in Moon Pond, 2003-2008.

	MOON POND											
	2003		2004		2005		2006		2007		2008	
n	*20*		*30*		*28*		*12*		*15*		*15*	
	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV
TOTAL NEKTON	78.52	107.10	27.10	45.43	38.75	46.66	36.58	23.85	47.60	19.04	64.73	70.37
CRUSTACEANS	70.25	102.59	18.87	33.99	20.11	31.77	25.08	19.94	38.87	20.65	27.80	35.48
FISH	13.56	12.41	8.23	16.53	18.64	26.51	11.50	11.49	8.73	1.60	36.60	45.06
American eel	0.29	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.09	0.00	0.00
Four-spine stickleback	1.05	2.22	1.47	2.81	3.36	5.61	0.42	0.79	2.97	3.06	0.13	0.52
Green crab	0.14	0.36	0.30	0.70	0.86	1.56	2.42	3.48	1.30	0.42	2.20	3.28
Sand shrimp	0.00	0.00	2.13	4.76	6.32	9.58	17.83	19.60	27.73	33.00	3.40	3.48
Say mud crab	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.14	0.00	0.00
Mummichog	7.81	11.22	3.90	11.42	12.14	22.11	6.08	7.98	3.20	1.70	10.73	10.27
Longnose spider crab	0.00	0.00	0.00	0.00	0.04	0.19	0.00	0.00	0.00	0.00	0.00	0.00
Spider crab species	0.00	0.00	0.03	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.77
Portly spider crab	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.09	0.00	0.00
Atlantic silverside	1.81	4.40	2.83	6.97	2.43	3.52	4.00	7.27	2.43	2.97	25.00	38.23
White perch	0.00	0.00	0.00	0.00	0.29	1.18	0.00	0.00	0.00	0.00	0.00	0.00
Long-clawed hermit crab	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.05	0.33	1.05
Shore shrimp	66.76	101.14	16.40	33.10	12.75	29.22	4.83	7.42	9.60	12.45	21.73	32.35
Atlantic mud crab	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.05	0.00	0.00
Winter flounder	0.00	0.00	0.00	0.00	0.11	0.31	0.50	0.90	0.00	0.00	0.67	1.11
Nine-spine stickleback	0.67	1.49	0.00	0.00	0.32	0.86	0.00	0.00	0.00	0.00	0.00	0.00
Pipe fish	0.00	0.00	0.03	0.18	0.00	0.00	0.50	0.90	0.07	0.09	0.27	0.46
Unknown crab species	0.00	0.00	0.00	0.00	0.14	0.45	0.00	0.00	0.00	0.00	0.00	0.00
Cunner	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.27
Lady Crab	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.46

Conclusions

The partial mitigation of the tidal restriction to the East Harbor ecosystem has allowed a diverse community of marine and estuarine species to colonize this previously freshwater habitat. The abundance of marine species continues to increase, especially in Moon Pond, which is expected due to the additional restriction of tidal flow between the two systems. The nekton community has been transformed from a low diversity, freshwater assemblage to a community that resembles that of a typical New England salt marsh. The increasing occurrences of commercially valuable species such as winter flounder further testify to the value of the partial tidal restoration. Analysis currently underway on all of CACO's nekton data will further elucidate the role of environmental factors in influencing the nekton community. We expect the community to continue to shift and stabilize slightly as more marine and estuarine species are able to colonize and become established in the lagoon.

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Additional, future projects for East Harbor

1. In 2009, studies similar to those conducted with *L. littorea* (periwinkle) will be conducted with *Ilyanassa obsoleta* (mud snail) – i.e., to evaluate the impact that this species can have on macroalgae growth if it were present in high numbers in the system.

2. It is still our intention to use prescribed fire to consume standing dead biomass in Moon Pond. This is expected to have several benefits. First, the removal of salt-killed vegetation from the floodplain will facilitate wider dispersal of seeds from native halophytes (Smith 2007). Secondly, it should greatly decrease resistance to water flow across the marsh with the effect that saltier water from the main tidal channel would be brought farther back into the marsh and, ultimately, accelerate the decline of *Phragmites* and various salt-intolerant plant species that still occupy a large portion of the wetland.

3. Benthic invertebrate monitoring and research will be conducted by students from Antioch University under the supervision of Dr. Rachel Thiet and Stephen Smith.